Paper A 1

ESTIMATE OF WINTER WHEAT YIELD FROM ERTS-1

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ABSTRACT

A model for estimating wheat yield per acre has been applied to acreage estimates derived from ERTS-1 imagery to project the 1973 wheat yields for a ten county area in southwest Kansas. The results (41.04 million bushels) are within 3 per cent of the preharvest estimates for the same area prepared by the USDA Statistical Reporting Service (39.91 million bushels). The projection from ERTS data is based on a visual enumeration of all detectable wheat fields in the study area and was completed while the harvest was in progress. Visual identification of winter wheat is readily achieved by using a temporal sequence of images (band 5 for Sept.-Oct.; band 5 for Dec.-Jan.; and band 5 & 7 for March-April). Identification can be improved by stratifying the project area into subregions having more or less homogeneous agricultural practices and crop mixes. By doing this, small changes in the spectral appearance of wheat related to soil type, irrigation, etc. can be accounted for. The interpretation rules developed by visual analysis can be automated for rapid computer surveys.

INTRODUCTION

Recent events in international politics have had great impact on the economy of U. S. agriculture. The "new" agricultural economics has focused attention on the need for rapid and timely estimates of crop acreage, yield, and general crop condition. Increasing world demand for U. S. agricultural products, coupled with increasing domestic demand, requires the development of means for assessing the status of major crops over large geographic areas at several points in the growing season. Even though present crop reporting methods are reliable for U. S. agriculture, a major shortcoming for efficient planning is the time lag between collection and dissemination of statistics. Techniques that can reduce the time lag in normal crop reporting procedures will undoubtedly have an impact on American agriculture. Similarly, any technique that will improve timeliness and accuracy of information on foreign agricultural production will benefit American agricultural policy makers. In this paper we describe our methods and results for estimating the winter wheat acreage and yield for a ten county area in southwest Kansas.

METHODOLOGY

Acreage, and yield per acre, represent the two measures required for a "crude" crop projection for any geographic area. We describe this as a crude projection because it does not consider differences in crop variety, protein content, crop lost during harvesting or other refinements on the amount of grain actually delivered to storage bins. Nevertheless, by using ERTS as the data base, projections can be announced several months in advance of current, equally crude, projections announced by the crop reporting service.

Wheat Acreage Estimates

A report on our technique for estimating winter wheat acreage in southwest Kansas was published in the Goddard Symposium on Significant Results using ERTS Imagery (Williams, et. al., 1973). In this document, a procedure for visually detecting and enumerating wheat fields on ERTS imagery is described.

Basically the technique requires the interpreter to:

1) delineate county boundaries on the imagery;

2) recognize and delineate agricultural subregions within each county on the basis of differences observed in the imagery (the boundaries of many of these subregions will cut across county boundaries;

3) compare the results of step 2 with soil and landform maps (for those counties where they exist) in order to better estimate the importance of the crop in each land-use region;

4) learn to distinguish the image tones of wheat in fields 80 acres (approx. 32 ha) or larger from those of other important crops in the subregion and convert these into interpretation rules applicable to that subregion, and;

5) visually locate and estimate the acreage of wheat fields in each subregion using the interpretation rules developed in step 4. From the subregion totals a composite acreage is obtained for the entire project area.

Accuracy and Advantages of ERTS Visual Analysis--By using the above procedure we have found through comparisons with ground truth and aircraft underflight data that 99 per cent of all the wheat fields and 99 per cent of the total acreage can be accurately estimated. Although the interpretation rules are created from grey tones of fields larger than 80 acres, the rules can be applied to all field sizes as small as 10 acres providing there is high tone contrast with their surroundings. An obvious advantage in the Winter Wheat Belt is that, once identified as wheat, the acreage of each field can be accurately estimated because field sizes, by the township and range system of survey, are characteristically 10, 40, 80, 120, 160 or 320 acres (4, 16, 32, 48, 64 or 128 ha respectively).

There are at least three other advantages of visual interpretation from ERTS. First, with experienced interpreters who are familiar with the cultivation of winter wheat, the time involved for a complete enumeration of each county is on the order of one hour per 250 square kilometers. While this is considerably longer than would be required using a computer (assuming it could be trained to identify wheat) it is also much cheaper. Secondly, by visual analysis, we obtain a nearly complete enumeration of the crop and learn how its spectral properties vary geographically and temporally. Thirdly, because we identify and locate each field early in the crop cycle, the need for ground truth and aircraft data diminishes through time and allows us to concentrate those activities in areas where spectral anomalies (disease, stress) begin to appear.

The Need for Sequential ERTS Data--Estimates of winter wheat acreage would not be possible without sequential ERTS data. The crop calendar for wheat is unique among those crops commonly grown in the Great Plains. It is planted in September or October depending upon weather conditions. By late November it is the only green crop in the agricultural scene and can be readily detected and enumerated on MSS band 5 (the chlorophyll absorption band). It is significant that these circumstance coincide with the most cloud-free season of the year over this region. With a high probability for at least one cloud and snow-free image,a complete enumeration of wheat planted is virtually a *fait accompli* . In addition, by virtue of slight tonal variations at this time of year, we feel that it will be possible, given more detailed observation, to categorize differences in planting time and general wheat condition.

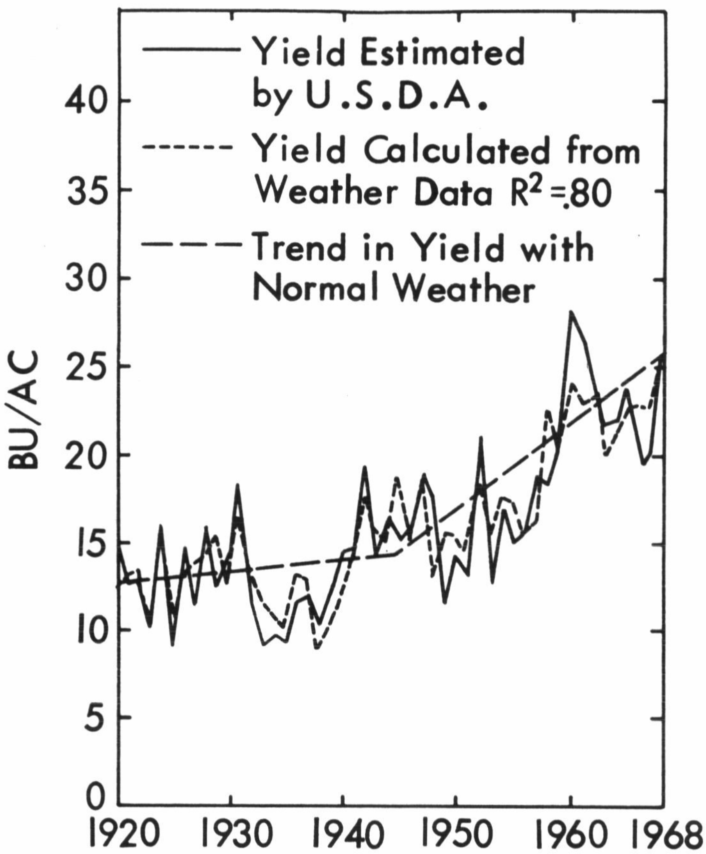
A second look at wheat is required during March or April in southwest Kansas. We used imagery from this time period to adjust the initial acreage estimate and to assess general wheat condition. This was necessary because a popular practice in western Kansas is to plant wheat as a winter forage and soil protection measure with no intention of later harvesting the crop. In spring the field is turned under to provide green manure and replanted to another crop. Such acreage must be subtracted from the initial estimate. A combination of the red and infrared bands is desired for these early spring observations.

A final ERTS observation is recommended during the harvest season. This is perhaps not as important at present as it could be in the future, after we learn to interpret and adjust estimates for crop loss due to disease, hail damage, etc. Individual fields can be turned under as late as June and still produce a cash crop. An estimate of wheat acreage actually harvested therefore is desirable. It is, of course, true that other crops, in addition to wheat, can be surveyed using the same set of above images. Alfalfa, for example, can be visually distinguished from wheat in May and early June on band 7. At this time of year alfalfa is growing vigorously (bright on band 7) while wheat is drying for harvest (medium tone on bands 5 and 7).

Yield Per Acre Estimate

The model we have used for estimating average yield per acre was proposed by Thompson (1969). It is based on departure from average weather conditions. According to his results,highest yields in Kansas are associated with above normal precipitation from August through March (normally a total of 325 mm.). Each additional 25 mm. at this time of year results in a gain of approximately 0.63 bushels per acre. High yields are also associated with above normal rainfall in April, normal rainfall in May and below normal rainfall in June. As a rule these months receive 88, 120 and 103 mm. of moisture respectively. Finally, for optimal yields in Kansas, below normal temperatures during April, May and June are best. With these data, it is possible to calculate an expected yield per acre. A comparison of actual and calculated yields is given in Figure 1.

ACTUAL AND CALCULATED YIELDS AND TREND OF WHEAT YIELD IN KANSAS (FROM THOMPSON, 1969)



Weather data suitable for use in the model are published by the U. S. Weather Bureau in its monthly climatological survey of each state. These data are published for each station and the stations are grouped into districts. The southwestern Kansas district includes the ten counties surveyed in this report and mean weather conditions in that district were used in solving the equation developed by Thompson.

Semi-Automatic Interpretation

The interpretation rules developed for visual interpretation can be specified in a computer compatible form for rapid wheat acreage surveys. At present the technique is termed semi-automatic because both the pre- and post-processing time involve human activities. In broad outline the procedure requires the interpreter to:

1) specify the coordinates of subareas on the image which match county boundaries or other geographic localities. Care must be taken to specify the location of towns or other non-cropland sites in order to exclude these from later tabulations.

2) create a frequency histogram for the 128 "tones" on the data tape for each area specified in step 1.

3) divide the histogram into 15 levels (roughly equivalent to the 15 gray level steps found on each MSS image).

4) determine the total number of resolution cells contained within those gray levels that have been determined by visual analysis to closely correspond to wheat. Since each resolution cell is approximately equal in size to one acre (.4 ha), the number of cells is considered to be roughly equal to the wheat acreage.

An estimate from this procedure for an 840 sq. mile (2,184 sq. km) area in Finney and Gray Counties totaled 165,000 acres. The same area, by visual tabulation, contained 162,000 acres. Although the time required for the semi-automatic approach was about half (10 hrs. vs. 5 hrs.), the cost was almost four times ($120 vs. $30). At present we do not consider these differences to be meaningful because of the research environment under which they all were derived. Our two strongest views at this stage of development are that:

1) we see no way of ever eliminating the pre-processing human time required for crop surveys, simply because there are too many decisions and "bookkeeping" operations involved in a reliable inventory, and;

2) we may require a visual analysis in any case so that we can locate and monitor individual fields.

RESULTS

Table 1 gives our estimate of wheat acreage for the ten county survey area (approximately 8,071 sq. miles or 21,000 km) and compares it with estimates prepared by the Statistical Reporting Service (SRS) of USDA. The ERTS estimate was prepared in March whereas the data available from SRS represent their May and August estimates of "harvestable" acreage. Final figures from SRS will not be available until February 1974, but, assuming that their August estimate is more accurate than their May estimate, the final tally should not differ significantly from the original ERTS total. The March ERTS estimate is within 0.5 per cent of the SRS August estimate.

Table 1

Comparative Estimates of 1973 Wheat Acreage (and yield in bu/ac)

for Ten Counties in SW Kansas

as Compiled by USDA, SRS and by Analysis of ERTS Imagery

	SRS			ERTS	
	Acreage Est.		Ave. Yield	Acreage Est.	
County	May 1973	Aug. 1973		March 1973	
Finney	205,000	198,000	(37)	239,000	
Grant	81,000	87,000	(34)	74,000	
Gray	157,000	162,000	(36)	174,000	
Haskell	104,000	109,000	(43)	110,000	
Kearney	117,000	119,000	(31)	115,000	
Meade	141,000	132,000	(36)	151,000	
Morton	91,000	97,000	(24)	72,000	
Seward	83,000	80,000	(36)	78,000	
Stanton	135,000	132,000	(24)	108,000	
Stevens	85,000	87,000	(31)	86,000	
	1,199,000	1,202,000	(33.2 ave.)	1,207,000	(34)

Also shown in Table 1, in parentheses, are the SRS projected average yields per acre, for August, for each of the ten counties. Our estimate for the entire area, as calculated by the Thompson model, is given in parentheses in the row of totals. These values have been combined into a matrix as shown in Table 2. The upper left cell represents the total crude yield that would be obtained using the traditional, time-tested techniques and an average of 33.2 bushels/ac. The lower right cell gives the expected wheat yield using ERTS imagery and the methodology reported in this paper. The ERTS estimate of total wheat bushels is 2.8 per cent higher than the SRS estimate. It predates the SRS estimate by about two months.

Table 2

Matrix of Total Estimated Yield

Comparing SRS and ERTS Data

Harvestable Acreage	Average Yield/Acre: SRS (33.2 bu/ac) as of 8/73	Average Yield/Acre: ERTS (34 bu/ac) as of 6/73
SRS (1.202×10^6) as of 8/73	39.906×10^6 bu	40.848×10^6 bu
ERTS (1.207×10^6) as of 3/73	41.193×10^6 bu	41.038×10^6 bu

DISCUSSION OF THE RESULTS

The above results include several points that need amplication. One could argue, first, that if the ERTS acreage estimate is based on a total enumeration of fields instead of a sample, as normally employed by SRS, and that, further, if SRS has a more sophisticated technique for calculating average yield per acre than that proposed by Thompson, the combination of these two values might give an even better estimated yield. This value is presented in the lower left cell of Table 2 and is approximately 3.1 per cent higher than the SRS tally. Final figures, when presented, may support this argument.

A second argument concerns the complex economics of irrigated wheat and wheat planted as winter forage. Irrigation by center pivot methods is increasing rapidly on the lighter textured soils of the southwest (Williams and Barker, 1972). In past years many irrigated fields have been planted to wheat as a winter cover crop and replanted in spring to feed grains. However, the recent high price of wheat, combined with the prospect for continued international wheat trading and low domestic reserves has stimulated growers to harvest wheat that would otherwise have been turned under. Yields on irrigated wheat fields in 1973 are estimated on the basis of past performance at 53 bushels/acre. We estimate from ERTS imagery that in 1973 174,000 acres of harvestable wheat were irrigated in the project area. Using these inputs we can revise the original yield estimate, as shown in Table 3, to a total of 44.344 million bushels, or 17 per cent higher than the August SRS estimate. Again, only the final figures, when released by SRS, will reveal whether this refinement is reasonable. No distinction is made between irrigated and dryland wheat in the SRS estimate presented but such distinction is made in the final February data. We believe that our ERTS derived estimate for harvestable irrigated wheat in 1973 is reasonable since SRS reported 202,000 acres of planted irrigated wheat in 1972 (personal communication).

Table 3

Revised Yield Estimate

from ERTS to Include Irrigated Acreage

Type	Acres ($\times 10^3$)	Ave. Yield (Bu/Ac)	Total Yield ($\times 10^6$ Bu)
Irrigated	174	53	9.222
Dryland	1033	34	35.122
Totals	1207	-	44.344

REFERENCES

ERTS-1 Imagery:

DATE	FRAME NUMBER	QUALITY
8-16-72	1024-16511-5	Excellent
9-21-72	1060-16505-5	Good, partial cloud cover
9-21-72	1060-16512-5	Good, partial cloud cover
9-22-72	1061-16564-5	Good
9-22-72	1061-16570-5	Good
12-21-72	1151-16575-5	Good, partial snow cover
3-20-73	1240-16523-5	Good, partial snow cover
5-31-73	1312-16520-5	Excellent
7-24-73	1366-16512-5	Excellent

Thompson, Louis M. (1969), "Weather and Technology in the Production of Wheat in the United States," Journ. of Soil and Water Conservation 24:6 (Nov.-Dec.), pp. 219-224.

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